

AD-A286 473



ARMY RESEARCH LABORATORY



Determination of Spectrally Resolved Transmittance and Extinction Coefficients for Obscurants at Smoke Week XIV

Frank T. Kantrowitz
Battlefield Environment Directorate

William M. Gutman and Troy D. Gammill
Physical Science Laboratory

ARL-TR-531

September 1994

DTIC QUALITY INSPECTED 5

94-35937



Approved for public release; distribution is unlimited.

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The citation of trade names and names of manufacturers in this report is not to be construed as official Government endorsement or approval of commercial products or services referenced herein.

Destruction Notice

When this document is no longer needed, destroy it by any method that will prevent disclosure of its contents or reconstruction of the document.

REPORT DOCUMENTATION PAGE			Form Approved OMB No 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</small>				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE September 1994	3. REPORT TYPE AND DATES COVERED Final		
4. TITLE AND SUBTITLE Determination of Spectrally Resolved Transmittance and Extinction Coefficients for Obscurants at Smoke Week XIV		5. FUNDING NUMBERS		
6. AUTHOR(S) Frank T. Kantrowitz William M. Gutman and Troy D. Gammill*				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Battlefield Environment Directorate ATTN: AMSRL-BE-E White Sands Missile Range, NM 88002-5501		8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-531		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory 2800 Powder Mill Road Adelphi, MD 20783-1145		10. SPONSORING/MONITORING AGENCY REPORT NUMBER		
11. SUPPLEMENTARY NOTES Physical Science Laboratory New Mexico State University Las Cruces, New Mexico 88003				
12a. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited		12b. DISTRIBUTION CODE		
13. ABSTRACT (Maximum 200 words) <p>Since the completion of Smoke Week XIII in May 1991, significant enhancements have been incorporated into the U.S. Army Research Laboratory, Battlefield Environment Directorate's Mobile Atmospheric Spectrometer (MAS). The key components of the MAS are a Fourier transform spectrometer and a 31-in Coudé telescope. The useful spectral coverage of the instrument is about 800 to 5000 cm^{-1} (2 to 12.5 μm). Although the instrument is capable of spectral resolution as high as 0.04 cm^{-1}, a resolution of 4 cm^{-1} was used during Smoke Week XIV. In preparation for Smoke Week XIV, a high-speed parallel spectrometer-to-computer interface was installed. Although this interface arrived too late to optimize fully, the increase in spectrometer performance was impressive. Rather than slewing on and off source, a mechanically chopped source was used to increase data acquisition rate and maintain a constant line of sight. With these two enhancements, the number of spectra collected increased by a factor of six. With more than 9,000 smoke spectra collected, a new data analysis approach was required. This requirement evolved into a three-dimensional spectral movie that displays transmittance (or radiance) versus spatial frequency as a function of time. In this manner, trials incorporating hundreds of spectra may be viewed. The MAS line of sight was in close proximity and parallel to the nephelometer grid. As a result, obscurant concentration length (CL) as determined from nephelometer data and transmittance as determined from MAS data have been manipulated to derive spectrally resolved mass extinction coefficients for selected obscurants.</p>				
14. SUBJECT TERMS spectroscopy, transmittance, radiance, concentration length, extinction coefficient		15. NUMBER OF PAGES 46		
		16. PRICE CODE		
17. SECURITY CLASSIFICATION Unclassified	18. SECURITY CLASSIFICATION Of this page	19. SECURITY CLASSIFICATION Of abstract	20. LIMITATION OF ABSTRACT SAR	

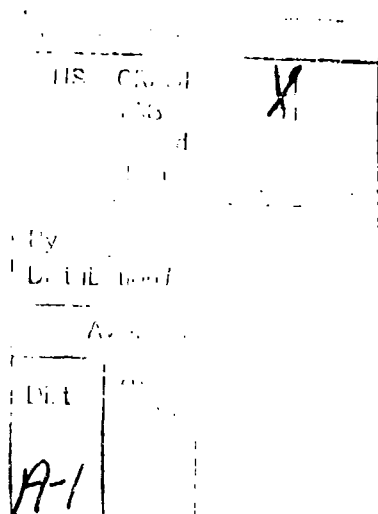
Contents

1. Background	3
2. Enhancements in Data Acquisition	5
3. Methodology	7
4. Instrumentation	9
4.1 Fourier Transform Spectrometer Configuration	9
4.2 Coudé Telescope	10
5. Data Reduction	13
6. Analysis Enhancements: Three-Dimensional Spectroscopic Movie	15
7. Example Spectra	17
8. Determination of Selected Spectrally Resolved Mass Extinction Coefficients	23
9. Concluding Remarks	27
References	29
Acronyms and Abbreviations	31
Distribution	33

Figures

1. Mobile atmospheric spectrometer (MAS)	4
2a. Red phosphorus transmittance spectra	18
2b. Red phosphorus radiance spectra	18
3. Graphite transmittance spectra	19
4. Kaolin transmittance spectra	19

5. Brass transmittance spectra	20
6. Aluminum transmittance spectra	20
7. Silica spectra as a function of time	21
8. Radiance spectra of a flare	21
9. Fog oil transmittance spectra	22
10. Spectrally resolved mass extinction coefficients for aluminum	25
11. Spectrally resolved mass extinction coefficients for graphite	26
12. Spectrally resolved mass extinction coefficients for brass	26
13. Spectrally resolved mass extinction coefficients for fog oil	24



1. Background

Obscurant tests traditionally have placed heavy emphasis on the use of broadband transmissometers in the characterization of optical properties of test materials. The broadband transmissometry has many attractive features, including high temporal resolution, relatively simple instrumentation, and relatively small data storage requirements. Unfortunately, it is impossible to match a transmissometer response function to the multitude of electro-optical systems that must contend with optically obscured battlefield environments. The inherent broadband nature of many transmissometers, therefore, severely limits the usefulness of such data. Researchers using such data are at a risk of formulating erroneous results.

Transmittance measurements made with the Battlefield Environment Directorate's (BED) Mobile Atmospheric Spectrometer (MAS) overcome this shortcoming of the broadband instruments. [2] While the traditional transmissometer can obtain only one transmittance data point per spectral window per time interval, a Fourier transform spectrometer (FTS) can provide hundreds of transmittance data points per spectral window per time interval. High-resolution FTS obscurant transmittance spectra can be convolved with *any* infrared system response function desired and thereby remove the uncertainty that accompanies the comparison of transmissometers with differing response functions. The result can be a more accurate prediction of the system performance.

The primary goal of the MAS support of Smoke Week XIV was to demonstrate the utility of spectrally resolved measurements in the obscurant test setting. The transmittance and radiance spectra of the obscurants and munitions have been made available to the scientific community through the Atmospheric Aerosols and Optics Data Library (AAODL). Nephelometer and transmittance data have been manipulated to derive obscurant mass extinction coefficients for selected materials. Figure 1 depicts the MAS.

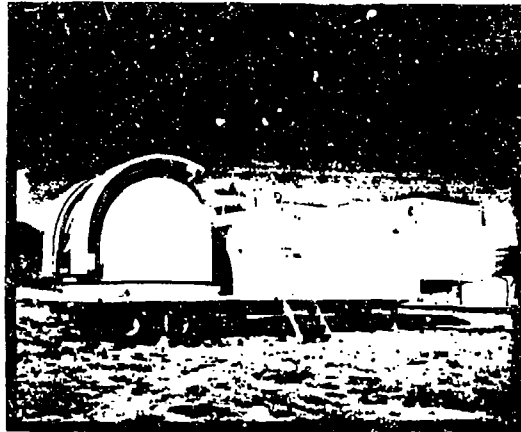


Figure 1. Mobile Atmospheric Spectrometer (MAS).

2. Enhancements in Data Acquisition

Significant enhancements were employed at Smoke Week XIV. [5] At Smoke Week XIII (1991) the spectrometer and host computer communicated via a serial interface. Before the system was shipped to Eglin Air Force Base for Smoke Week XIV (1992), a high-speed parallel interface was installed. Because of the lack of time to become familiar with this upgrade, the system was not optimized to its fullest extent; however, the increase in data acquisition rates was exceptional.

A second enhancement dealt with the method for obtaining source and path radiance spectra. During Smoke Week XIII the telescope had to repeatedly cycle from on-source to 0.5° off-source which changed the background and was an inefficient use of time. For Smoke Week XIV a source chopper was employed. Communications from the host computer to the chopper were accomplished via communications wire.

3. Methodology

The transmittance of a sample of material at radiation frequency ν is defined as the ratio of the radiant power at frequency ν exiting the material to the radiant power at that frequency incident upon the material

$$T(\nu) = \frac{I(\nu)}{I_o(\nu)}. \quad (1)$$

For an obscurant measurement, the transmittance through the path with the obscurant relative to the clear air path is required rather than the absolute transmittance of the entire path. The spreading factors and the instrument response function remain unchanged when comparing the path with the obscurant to the path without the obscurant; however, a simpler measurement methodology can be applied. Without path radiance and background effects, the relative transmittance of the obscurant is the point-by-point ratio of the obscurant spectrum to the clear air spectrum. Path radiance and background radiation may contaminate the raw signals and thus must be removed.

$$I_o(\nu) = S_{\text{clear}} - S_{\text{bkg}}$$

and

$$I(\nu) = S_{\text{obs}} - S_{\text{path}}$$

therefore,

$$T(\nu) = \frac{S_{\text{obs}} - S_{\text{path}}}{S_{\text{clear}} - S_{\text{bkg}}}. \quad (2)$$

All the quantities of S are functions of ν .

An effective measurement methodology is to measure the four quantities of S over as short an interval as practical. It is especially important for the obscurant and path radiance data to be close together in time because of the transient nature of the typical obscurant cloud. Clear air data

may be acquired before or after the obscurant is present; but, in general, pretrial clear air data are less likely to be contaminated by residual obscurant that may not be obvious to an observer. In repetitive, alternating sequence, obscurant spectra and path radiance spectra are collected. Path radiance spectra can be obtained by blocking the source or pointing the collecting telescope slightly off the source. Pointing the collecting telescope slightly off the source was used at Smoke Week XIII. To enhance the data acquisition rates, a source chopper was incorporated into the system for Smoke Week XIV.

4. Instrumentation

The key components of the MAS for support of the activities at Smoke Week XIV were the FTS and the 31-in Coudé telescope.

4.1 Fourier Transform Spectrometer Configuration

The MAS FTS consists of a scanning Michelson interferometer with associated optics and control electronics and a dedicated computer system. Depending on the detector, beamsplitter, and source in use, the spectrometer can cover a segment of the spectral region from about 700 to 20,000 cm^{-1} (0.5 to 14 μm).

The Fourier spectrometer was configured with a potassium bromide (KBr) substrate beamsplitter with a mercury-cadmium telluride (MCT) detector. The useful spectral coverage was about 800 to 5000 cm^{-1} (2 to 12.5 μm). Although the instrument is capable of spectral resolution as high as 0.04 cm^{-1} , a resolution of 4 cm^{-1} was used during Smoke Week XIV. Very high resolution is not needed or practical for most obscurant transmittance measurements because of time resolution considerations.

There are 234 data points in the 800- to 1250- cm^{-1} spectral region, 114 points in the 2020- to 2240- cm^{-1} spectral region, 316 points in the 2390- to 3000- cm^{-1} spectral region, and 492 points in the 4050- to 5000- cm^{-1} spectral region.

A factor in choosing the instrument configuration was that a KBr beamsplitter was clearly the best choice for most mid-infrared work, but KBr is hygroscopic. Great care must be exercised to avoid damage during humid weather and especially during periods of precipitation. Since a KBr beamsplitter was damaged beyond use during a period of high humidity during Smoke Week XIII, both a replacement KBr beamsplitter and a moisture-insensitive (ZnSe) beamsplitter were in the MAS inventory for Smoke Week XIV. The KBr beamsplitter was used during all tests because the test site experienced good weather and the ZnSe beamsplitter was insensitive to radiation shorter than 3 μm .

When time permitted, between trials, the data acquisition sequence for each trial included high signal-to-noise ratio clear air source and clear air background data. For all clear air data, 100 instrument scans were coadded. Each interferogram required about 35 s to acquire, with another 2.3 s required for transfer and storage. For most trials, clear air data acquisition was initiated at about T - 3 min, and two complete cycles were performed. When time permitted, a similar post-test clear air acquisition sequence was carried out.

Obscurant and path radiance interferograms were obtained by coaddition of two scans. Coaddition of two scans required 0.7 s. Transfer and storage again required about 2.3 s per interferogram. Each interferogram, therefore, required 3 s to acquire and store. Each complete measurement cycle of obscurant and path radiance interferograms required 6 s.

Coaddition of multiple instrument scans serves two important functions: (1) it improves the signal-to-noise ratio of the interferograms and the resulting spectra (the signal-to-noise ratio increases proportionally with the square root of the number of instrument scans coadded), and (2) it reduces the signal variation that results from atmospheric turbulence.

The usual MAS sources are a quartz-halogen lamp and a temperature controlled blackbody that can reach 1000 °C. In either case, the radiation is collimated with a modified searchlight. The blackbody is the source of choice for most of the mid-infrared region, while the lamp provides better performance for wavelengths shorter than 2 μm . Therefore, the near-infrared and mid-infrared regions require different sources, and only one region can be optimized at a time.

4.2 *Coudé Telescope*

The MAS Coudé-mounted telescope is a classical Cassegrain telescope consisting of a 31-in diameter parabolic primary mirror and a 6-in diameter hyperbolic secondary mirror. Segments of the optical path are coaxial with the elevation and azimuth rotational axes of the telescope so the beam position on the optical bench is invariant with respect to the pointing.

The telescope uses a sophisticated servo loop control system. The angular resolution is 1.24 arc-s. A desktop computer provides the user interface. A control program has been written to translate simplified commands into valid telescope instructions. The telescope control program provides the capability to fine-tune the pointing to optimize the signal. Once the correct coordinates have been found, it is very easy to return to a given position with high precision.

5. Data Reduction

Programs written in Fortran were used to reduce all data, and MS-DOS-based computers acted as hosts. Batch-oriented data analysis programs were produced and fine-tuned before Smoke Week XIV.

Because data acquisition required only 0.7 s, a data file can be thought of as a snapshot of the changing spectrum at the time listed in the file header. The spectral intervals in which atmospheric opacity significantly impaired the ability to retrieve the obscurant transmittance are not included in the files, and breaks in the listings are used to delineate the resulting discontinuities in the spectral coverage.

6. Analysis Enhancements: Three-Dimensional Spectroscopic Movie

With more than 9,000 spectra collected, the next significant task was data analysis. In the past, the only means a researcher had to view data were commercial plot packages in which a few spectra could be displayed. A decision was made that with such a large volume of data a new approach was required. The requirement evolved into a three-dimensional (3-D) spectral movie that displays transmittance (or radiance) versus spatial frequency as a function of time. Complete trials incorporating hundreds of spectra may be viewed in a movie. The aspect angle may be changed during operation. A version of the program under development permits the movie to be paused at any time, reversed or zoomed.

7. Example Spectra

MAS spectra provide useful insight into the behavior of the obscurant materials. Frequency dependence of the smoke transmittance that cannot be observed with broadband transmissometers is readily apparent in the spectra.

In general, in the mid-infrared, some materials exhibit only a smooth falloff with increasing frequency. Others, however, exhibit a wealth of interesting detail. Among the materials investigated were red phosphorus (figures 2a, 2b), graphite (figure 3), kaolin (figure 4), brass (figure 5), aluminum (figure 6) and silica (3-D figure 7). Radiance spectra of munitions and a flare were taken at Smoke Week XIV. In the 3-D spectra of a flare (figure 8), note the red spike (2240 cm^{-1}) and blue spike (2390 cm^{-1}) due to heated atmospheric CO_2 . The presence of two small emission features at 4275 and 4530 cm^{-1} is also of interest, though not understood at this time. Some fog oil spectra (figure 9) exhibit the well-known C—H stretch vibrational-rotational band at about 2800 cm^{-1} .

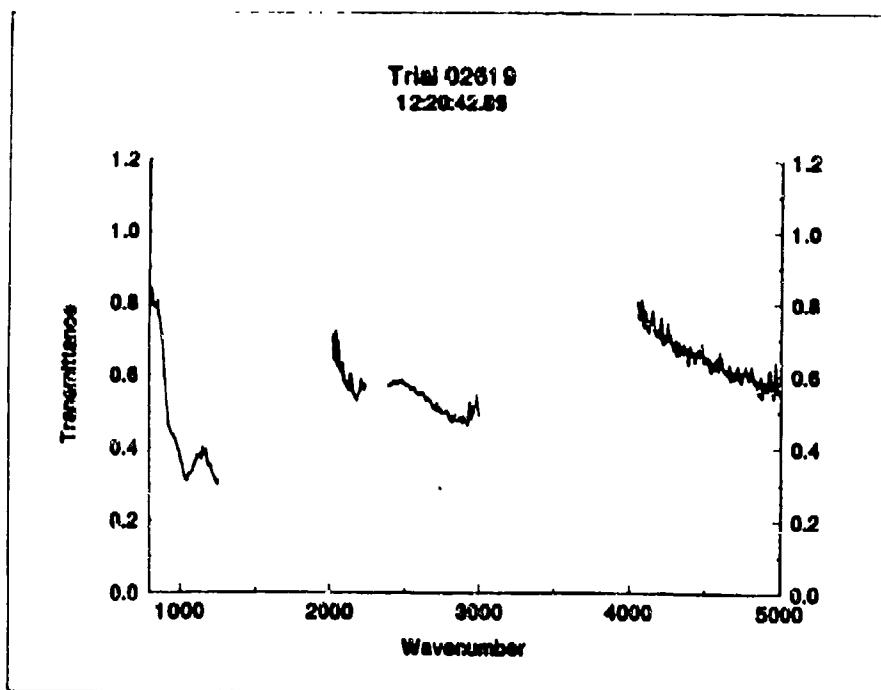


Figure 2a. Red phosphorus transmittance spectra.

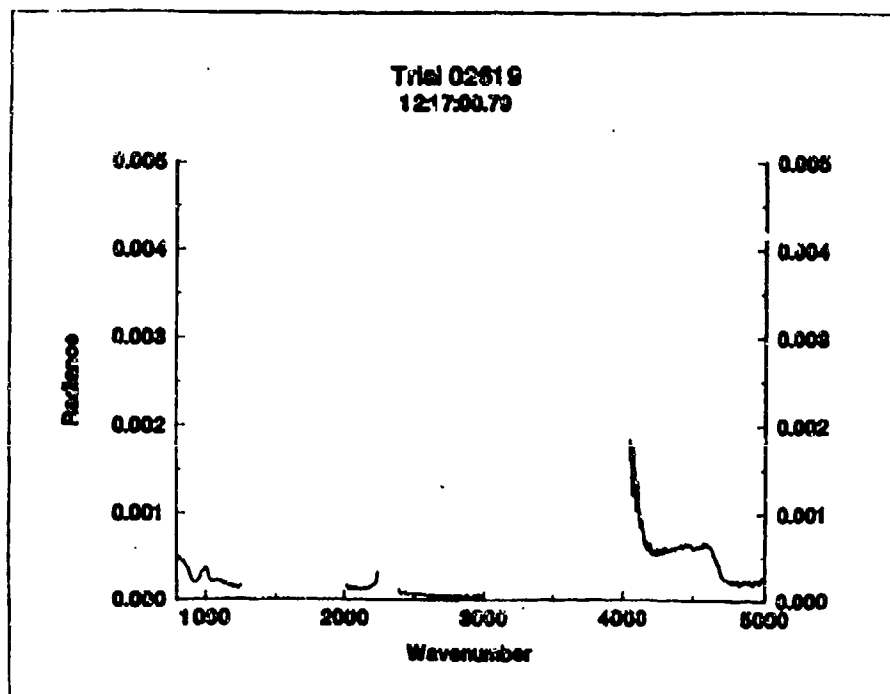


Figure 2b. Red phosphorus radiance spectra.

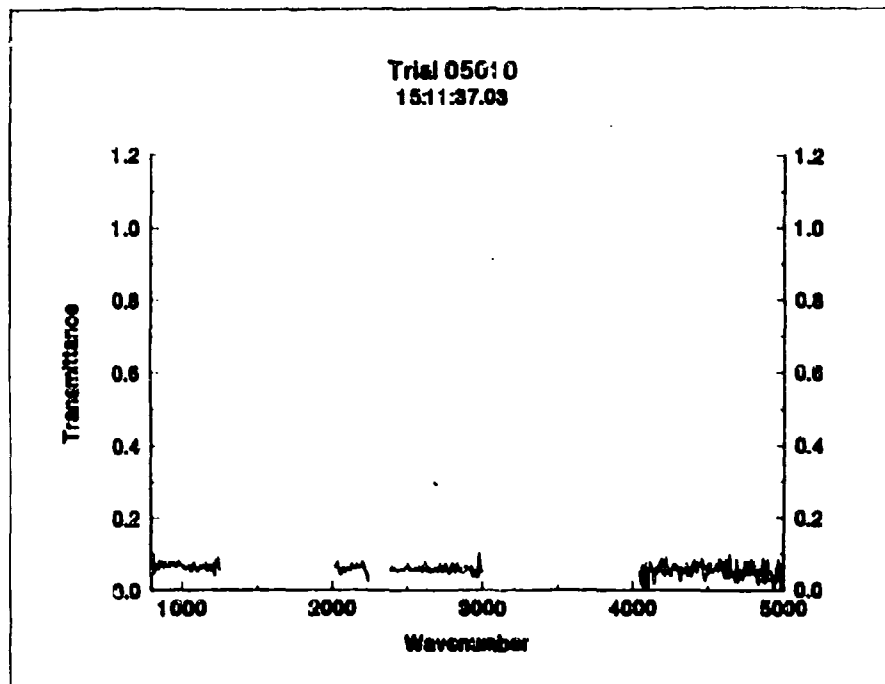


Figure 3. Graphite transmittance spectra.

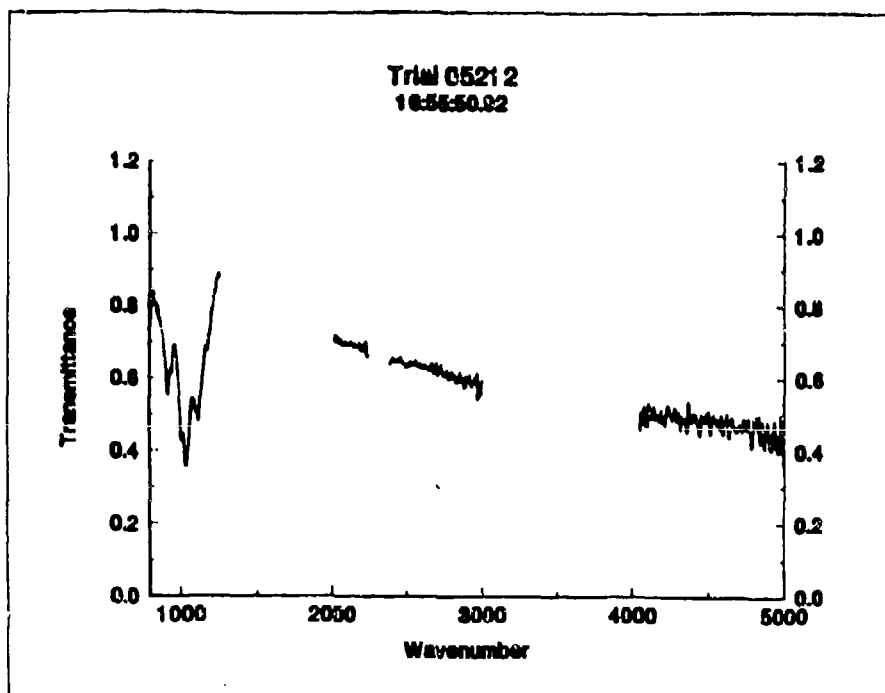


Figure 4. Kaolin transmittance spectra.

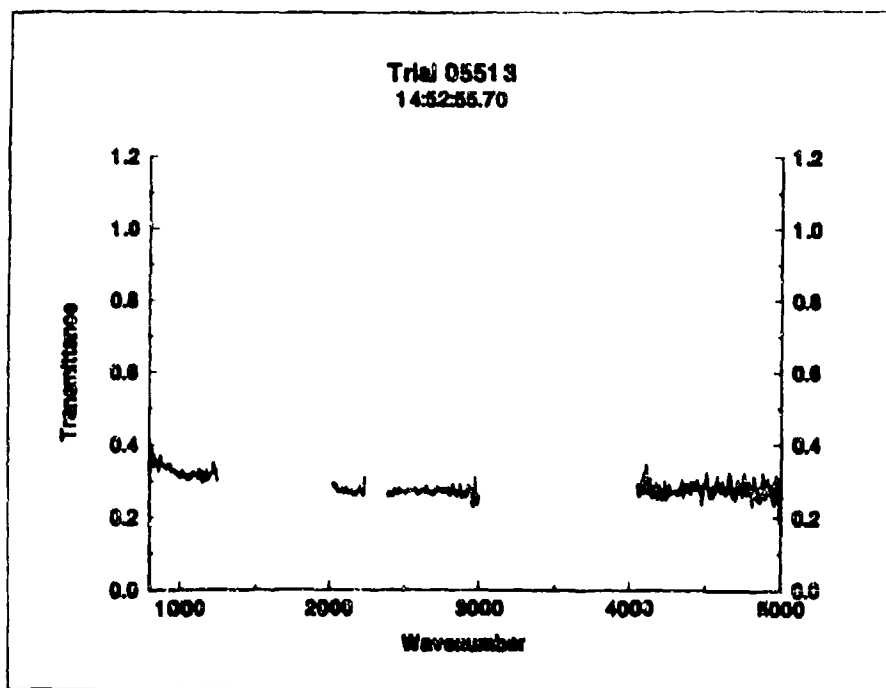


Figure 5. Brass transmittance spectra.

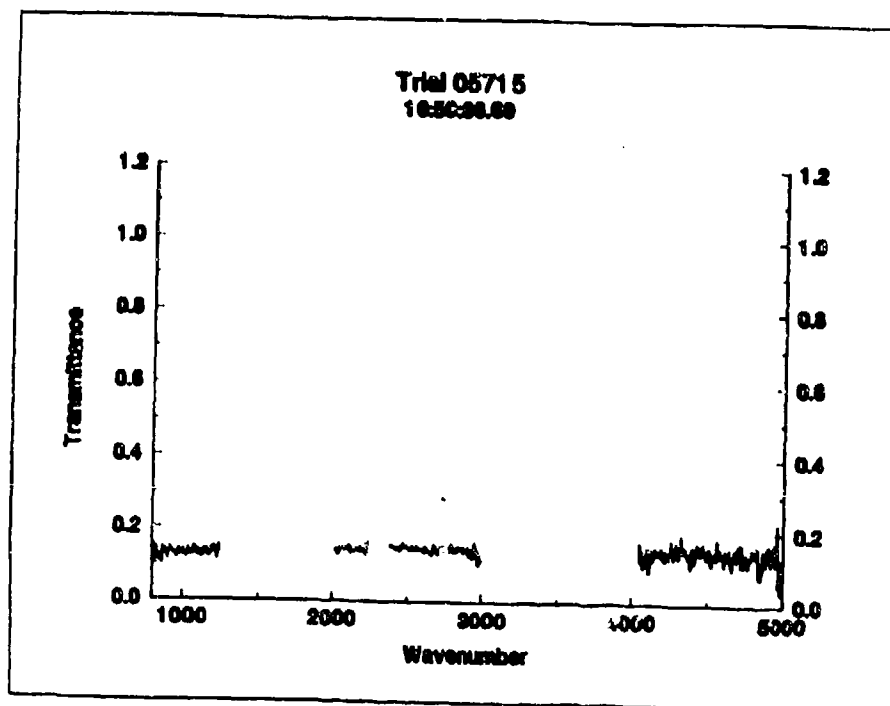


Figure 6. Aluminum transmittance spectra.

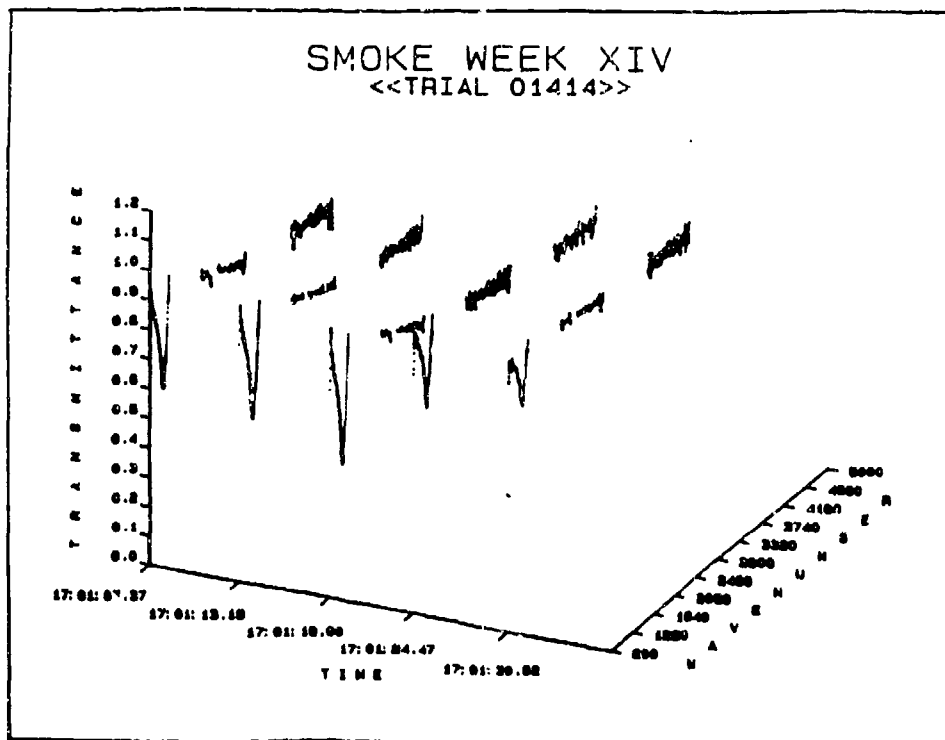


Figure 7. Silica spectra as a function of time.

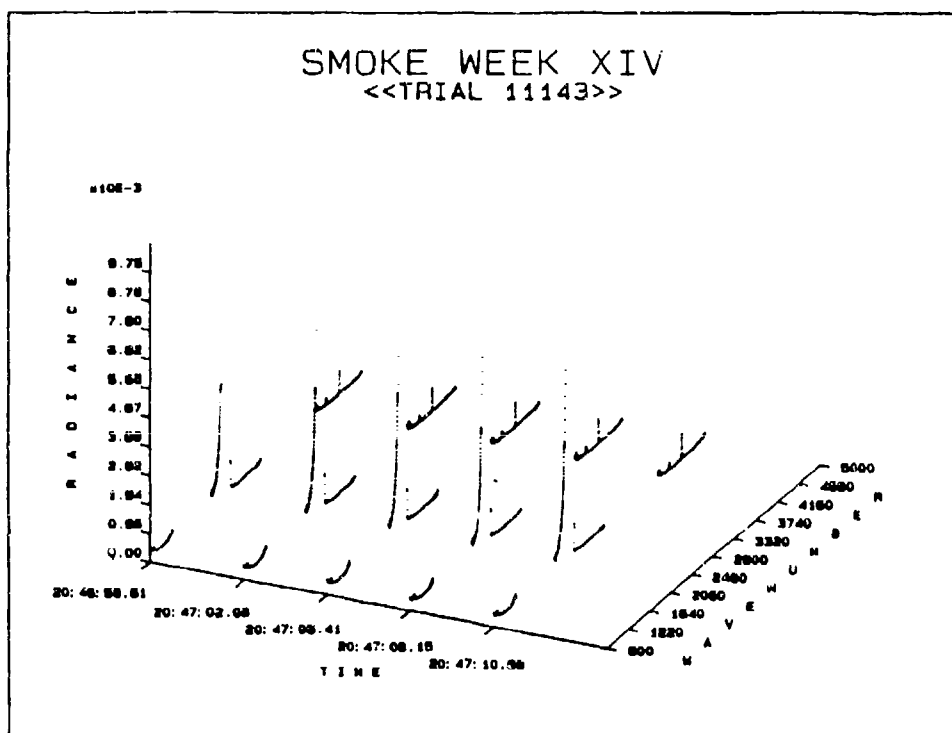


Figure 8. Radiance spectra of a flare.

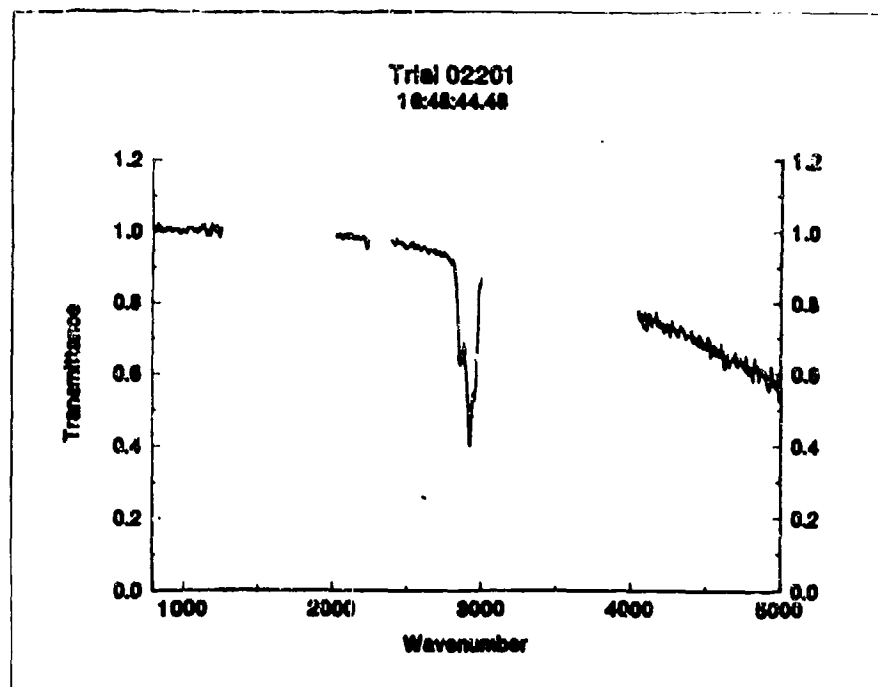


Figure 9. Transmittance spectra of fog oil.

8. Determination of Selected Spectrally Resolved Mass Extinction Coefficients

The MAS line of sight was in close proximity and parallel to the nephelometer grid. As a result, obscurant concentration length (CL) as determined from nephelometer data and transmittance as determined from MAS data have been manipulated to derive spectrally resolved mass extinction coefficients for selected obscurants. A word of caution -- few coefficient spectra have been analyzed. The preliminary results presented here may not be typical of all data. Mass extinction coefficients have been derived from measurements made at Smoke Week XIII (1991) using the ARL broadband Multipath Transmissometer/Radiometer (MPTR). [3] These results, along with coefficients maintained in the ARL Electro-Optical Systems Atmospheric Effects Library (EOSAEL) [4] are compared with MAS derived data. The MAS data show breaks where the atmosphere is opaque. As a result, the data tend to become noisy at the break points. Also, since the MAS detector response is peaked in the 8- to 12- μm (800 to 1250 cm^{-1}) region, the response is lower and the data are more noisy at shorter wavelengths (higher frequencies). MAS and MPTR data compare favorably for aluminum (figure 10). Results from MAS and EOSAEL data for graphite (figure 11) also appear promising. The MPTR 3- to 5- μm band average for brass (figure 12) differs from MAS data to some extent. Compounding the problem, some researchers (Bruce, 1993) report results as high as 1.8 m^2/g .*

The fog oil results (figure 13) demonstrate the utility of spectrally resolved measurements. While the EOSAEL band averaged data compare with the MAS data in the 8- to 2- μm region, the band average in the 3- to 5- μm region does not compare well with the spectrally resolved MAS data. Fog oil exhibits the well-known hydrocarbon stretch vibrational-rotational band at about 2800 cm^{-1} .

*C. W. Bruce, 1993, Private communication, U.S. Army Research Laboratory, Battle-field Environment Directorate, White Sands Missile Range, NM 88001-5501.

For a parallel arrangement, nephelometer-based mass concentrations and transmittance measurements are related according to Beer's law:

$$T(t) = e^{(-\alpha CL(t+\Delta t))} \quad (3)$$

where:

T = transmittance

t = time

Δt = time for cloud to move from spectrometer line of sight to nephelometer grid

α = Mass extinction coefficient in m^2/g

CL = Concentration Length in g/m^2

The concentration length is described as follows:

$$CL(t) = \int C(r,t) dr \quad (4)$$

where:

$C(r,t)$ = Obscurant mass concentration at distance r along the nephelometer grid at time t

dr = change in position

L = path length as determined by the nephelometers

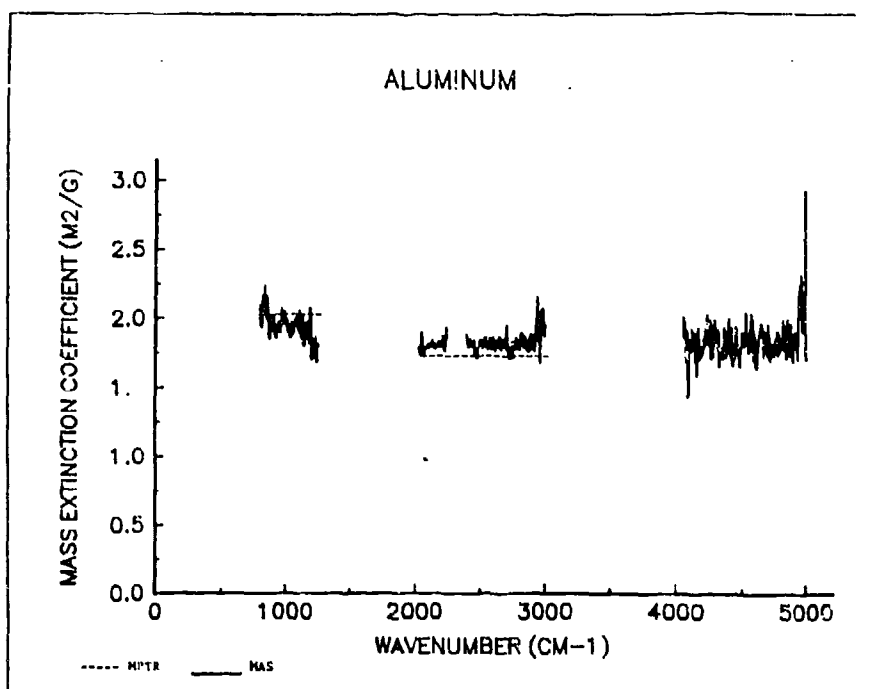


Figure 10. Spectrally resolved mass extinction coefficients for aluminum.

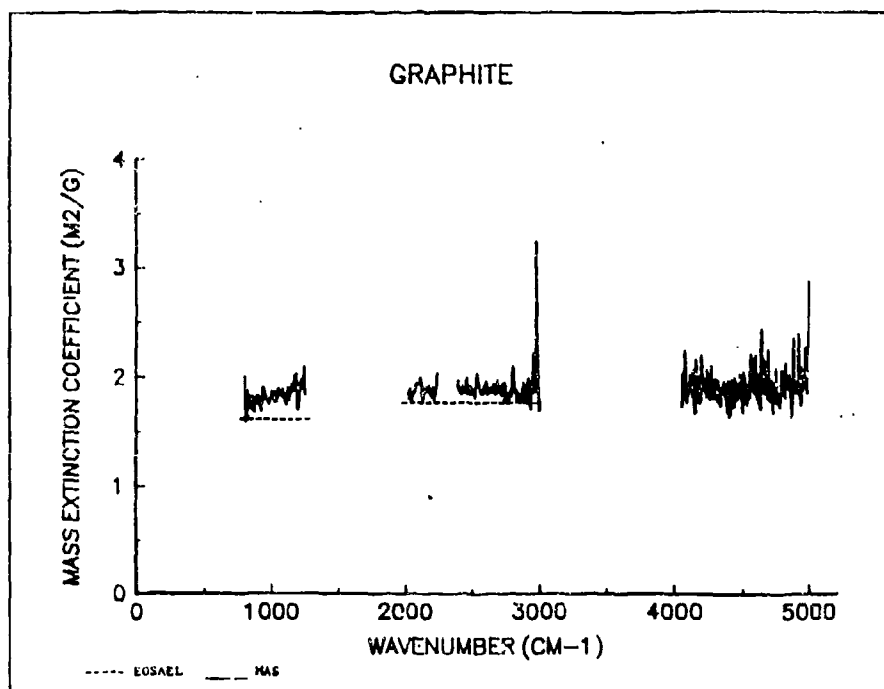


Figure 11. Spectrally resolved mass extinction coefficients for graphite.

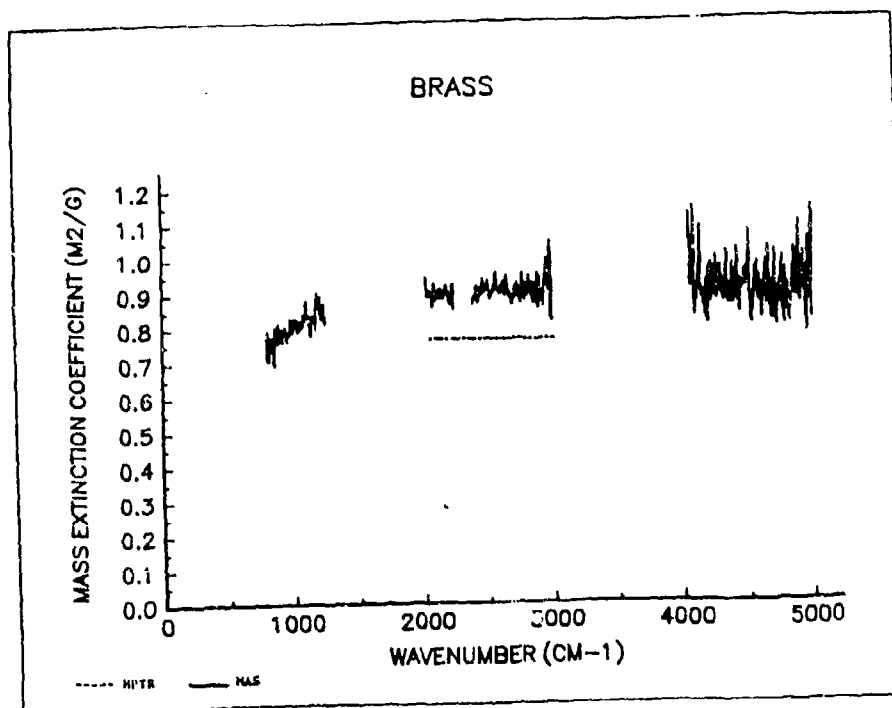


Figure 12. Spectrally resolved mass extinction coefficients for brass.

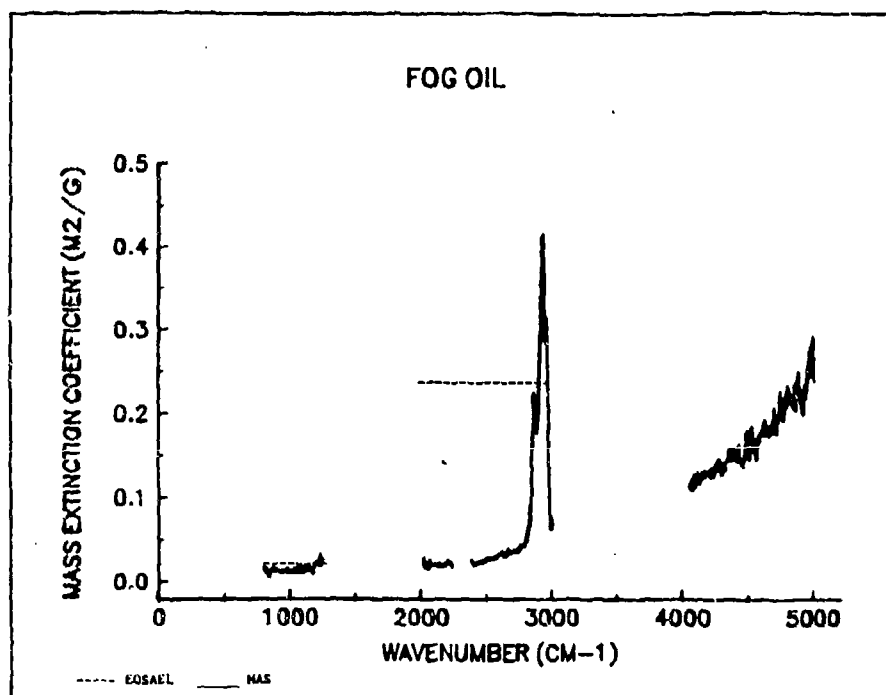


Figure 13. Spectrally resolved mass extinction coefficients for fog oil.

9. Concluding Remarks

All the reduced spectra were provided to the managers of the AAODL database. Each spectrum was provided in two column, comma delimited, ASCII format. The first column is the spatial frequency (wave number) in centimeters⁻¹ of each point, and the second column is the transmittance (percent) or radiance (W/cm²/sr/cm⁻¹).

Among the enhancements employed at Smoke Week XIV were a high-speed parallel spectrometer-to-computer interface and a mechanical chopper at the blackbody source. While these enhancements were not fully optimized, they accounted for a dramatic increase in data acquisition rate and the total number of spectra obtained.

More than 9,000 spectra were collected, and analysis will be a significant task. A 3-D spectral movie that displays transmittance (or radiance) versus spatial frequency as a function of time has been developed, which allows the researcher to view complete trials incorporating hundreds of spectra.

Characterization of obscurant mass extinction coefficients has demonstrated the utility of spectrally resolved measurements.

Recently, a new system has been added to the MAS inventory. The smaller, 4-wheel drive, off-road MAS ROVER provides greater mobility for fence line and general spectroscopic monitoring. All electronics are powered by 2 banks of 12 V marine batteries. The portable spectrometer with 0.26-m optics monitors in passive or active (double-ended) modes.

References

1. Gutman, W. M., et al., 1991, "Spectrally Resolved Transmittance Measurements at SMOKE Week XIII." *Proceedings of the 1991 Battlefield Atmospheric Conference*, U.S. Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM 88002-5501.
2. Kantrowitz, F. T., W. M. Gutman, T. D. Gammill, J. V. Rice, 1992, "The Mobile Atmospheric Spectrometer: Enhancements in Data Acquisition and Analysis For Smoke Week XIV." *Proceedings of the 1992 Battlefield Atmospheric Conference*, U.S. Army Research Laboratory, Battlefield Environment Directorate, White Sands Missile Range, NM 88002-5501.
3. Haines, D. C., 1992, *Data Comparison For Smoke Week XIII For Nephelometer and Multipath Transmissometer/Radiometer* (data Report Prepared for Atmospheric Sciences Laboratory), Physical Science Laboratory, Las Cruces, NM 88003-0002.
4. Hoock, D. W., R. A. Sutherland, and D. Clayton, 1987, *EOSAEL 87 Volume II: Combined Obscuration Model For Battlefield-Induced Contaminants (COMBIC)*, ASL-TR-0221-11, U.S. Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM 88002-5501.

Acronyms

AAODL	Atmospheric Aerosols and Optics Data Library
ARL	Army Research Laboratory
BED	Battlefield Environment Directorate
CL	concentration length
EOSAEL	Electro-Optical Systems Atmospheric Effects Library
FTS	Fourier transform spectrometer
KBr	potassium bromide
MAS	mobile atmospheric spectrometer
MCT	mercury-cadmium telluride
MPTR	multipath transmissometer/radiometer
ZnSe	Zinc Selenide

DISTRIBUTION

Copies

Commandant U.S. Army Chemical School ATTN: ATZN-CM-CC (Mr. Barnes) Fort McClellan, AL 36205-5020	1
NASA Marshal Space Flight Center Deputy Director Space Science Laboratory Atmospheric Sciences Division ATTN: E501 (Dr. Fichtl) Huntsville, AL 35802	1
NASA/Marshall Space Flight Center Atmospheric Sciences Division ATTN: Code ED-41 Huntsville, AL 35812	1
Deputy Commander U.S. Army Strategic Defense Command ATTN: CSSD-SL-L (Dr. Lilly) P.O. Box 1500 Huntsville, AL 35807-3801	1
Deputy Commander U.S. Army Missile Command ATTN: AMSMI-RD-AC-AD (Dr. Peterson) Redstone Arsenal, AL 35898-5242	1
Commander U.S. Army Missile Command ATTN: AMSMI-RD-DE-SE (Mr. Lill, Jr.) Redstone Arsenal, AL 35898-5245	1
Commander U.S. Army Missile Command ATTN: AMSMI-RD-AS-SS (Mr. Anderson) Redstone Arsenal, AL 35898-5253	1

Commander
U.S. Army Missile Command
ATTN: AMSMI-RD-AS-SS (Mr. B. Williams) 1
Redstone Arsenal, AL 35898-5253

Commander
U.S. Army Missile Command
Redstone Scientific Information Center
ATTN: AMSMI-RD-CS-R/Documents 1
Redstone Arsenal, AL 35898-5241

Commander
U.S. Army Intelligence Center
and Fort Huachuca
ATTN: ATSI-CDC-C (Mr. Colanto) 1
Fort Huachuca, AZ 85613-7000

Northrup Corporation
Electronics Systems Division
ATTN: Dr. Tooley 1
2301 West 120th Street, Box 5032
Hawthorne, CA 90251-5032

Commander
Pacific Missile Test Center
Geophysics Division
ATTN: Code 3250 (Mr. Battalino) 1
Point Mugu, CA 93042-5000

Commander
Code 3331
Naval Weapons Center
ATTN: Dr. Shlanta 1
China Lake, CA 93555

Lockheed Missiles & Space Co., Inc.
Kenneth R. Hardy
ORG/91-01 B/255 1
3251 Hanover Street
Palo Alto, CA 94304-1191

Commander
Naval Ocean Systems Center
ATTN: Code 54 (Dr. Richter) 1
San Diego, CA 92152-5000

Meteorologist in Charge
Kwajalein Missile Range
P.O. Box 67 1
APO San Francisco, CA 96555

U.S. Department of Commerce Center
Mountain Administration
Support Center, Library, R-51
Technical Reports
325 S. Broadway 1
Boulder, CO 80303

Dr. Hans J. Liebe
NTIA/ITS S 3
325 S. Broadway 1
Boulder, CO 80303

NCAR Library Serials
National Center for Atmos Research
P.O. Box 3000 1
Boulder, CO 80307-3000

Headquarters
Department of the Army
ATTN: DAMI-POI 1
Washington, DC 20310-1067

Mil Asst for Env Sci Ofc of
the Undersecretary of Defense
for Rsch & Engr/R&AT/E&LS
Pentagon - Room 3D129 1
Washington, DC 20301-3080

Headquarters
Department of the Army
DEAN-RMD/Dr. Gomez 1
Washington, DC 20314

Director
Division of Atmospheric Science
National Science Foundation
ATTN: Dr. Bierly 1
1800 G. Street, N.W.
Washington, DC 20550

Commander
Space & Naval Warfare System Command
ATTN: PMW-145-1G 1
Washington, DC 20362-5100

Cominadant
U.S. Army Infantry
ATTN: ATSH-CD-CS-OR (Dr. E. Dutoit) 1
Fort Benning, GA 30905-5090

USAFETAC/DNE 1
Scott AFB, IL 62225

Air Weather Service
Technical Library - FL4414 1
Scott AFB, IL 62225-5458

USAFETAC/DNE
ATTN: Mr. Glauber 1
Scott AFB, IL 62225-5008

Headquarters
AWS/DOO 1
Scott AFB, IL 62225-5008

Commander
U.S. Army Combined Arms Combat
ATTN: ATZL-CAW 1
Fort Leavenworth, KS 66027-5300

Commander
U.S. Army Space Institute
ATTN: ATZI-SI 1
Fort Leavenworth, KS 66027-5300

Commander
U.S. Army Space Institute
ATTN: ATZL-SI-D
Fort Leavenworth, KS 66027-7300

1

Commander
Phillips Lab
ATTN: PL/LYP (Mr. Chisholm)
Hanscom AFB, MA 01731-5000

1

Director
Atmospheric Sciences Division
Geophysics Directorate
Phillips Lab
ATTN: Dr. McClatchey
Hanscom AFB, MA 01731-5000

1

Raytheon Company
Dr. Sonnenschein
Equipment Division
528 Boston Post Road
Sudbury, MA 01776
Mail Stop 1K9

1

Director
U.S. Army Materiel Systems Analysis Activity
ATTN: AMXSU-CR (Mr. Marchetti)
Aberdeen Proving Ground, MD 21005-5071

1

Director
U.S. Army Materiel Systems Analysis Activity
ATTN: AMXSU-MP (Mr. Cohen)
Aberdeen Proving Ground, MD 21005-5071

1

Director
U.S. Army Materiel Systems Analysis Activity
ATTN: AMXSU-AT (Mr. Campbell)
Aberdeen Proving Ground, MD 21005-5071

1

Director
U.S. Army Materiel Systems
Analysis Activity
ATTN: AMXSY-CS (Mr. Bradley) 1
Aberdeen Proving Ground, MD 21005-5071

Director
ARL Chemical Biology
Nuclear Effects Division
ATTN: AMSRL-SL-CO 1
Aberdeen Proving Ground, MD 21010-5423

Army Research Laboratory
ATTN: AMSRL-D 1
2800 Powder Mill Road
Adelphi, MD 20783-1145

Army Research Laboratory
ATTN: AMSRL-OP-SD-TP 1
Technical Publishing
2800 Powder Mill Road
Adelphi, MD 20783-1145

Army Research Laboratory
ATTN: AMSRL-OP-CI-SD-TL 1
2800 Powder Mill Road
Adelphi, MD 20783-1145

Army Research laboratory
ATTN: AMSRL-SS-SH 1
(Dr. Sztankay)
2800 Powder Mill Road
Adelphi, MD 20783-1145

National Security Agency
ATTN: W21 (Dr. Longbothum) 1
9800 Savage Road
Fort George G. Meade, MD 20755-6000

OIC-NAVSWC
Technical Library (Code E-232) 1
Silver Springs, MD 20903-5000

Commander
U.S. Army Research office
ATTN: DRXRO-GS (Dr. Flood) 1
P.O. Box 12211
Research Triangle Park, NC 27009

Dr. Jerry Davis
North Carolina State University
Department of Marine, Earth, and
Atmospheric Sciences 1
P.O. Box 8208
Raleigh, NC 27650-8208

Commander
U.S. Army CECRL
ATTN: CECRL-RG (Dr. Boyne) 1
Hanover, NH 03755-1290

Commanding Officer
U.S. Army ARDEC
ATTN: SMCAR-IMI-I, Bldg 59 1
Dover, NJ 07806-5000

Commander
U.S. Army Satellite Comm Agency
ATTN: DRCPM-SC-3 1
Fort Monmouth, NJ 07703-5303

Commander
U.S. Army Communications-Electronics
Center for EW/RSTA
ATTN: AMSEL-EW-MD 1
Fort Monmouth, NJ 07703-5303

Commander
U.S. Army Communications-Electronics
Center for EW/RSTA
ATTN: AMSEL-EW-D 1
Fort Monmouth, NJ 07703-5303

Commander
U.S. Army Communications-Electronics
Center for EW/RSTA
ATTN: AMSEL-RD-EW-SP 1
Fort Monmouth, NJ 07703-5206

Commander
Department of the Air Force
OL/A 2d Weather Squadron (MAC) 1
Holloman AFB, NM 88330-5000

PL/WE 1
Kirtland AFB, NM 87118-6008

Director
U.S. Army TRADOC Analysis Center
ATTN: ATRC-WSS-R 1
White Sands Missile Range, NM 88002-5502

Director
U.S. Army White Sands Missile Range
Technical Library Branch
ATTN: STEWS-IM-IT 3
White Sands Missile Range, NM 88002

Army Research Laboratory
ATTN: AMSRL-BE (Mr. Veazy) 1
Battlefield Environment Directorate
White Sands Missile Range, NM 88002-5501

Army Research Laboratory
ATTN: AMSRL-BE-A (Mr. Rubio) 1
Battlefield Environment Directorate
White Sands Missile Range, NM 88002-5501

Army Research Laboratory
ATTN: AMSRL-BE-M (Dr. Niles) 1
Battlefield Environment Directorate
White Sands Missile Range, NM 88002-5501

Army Research Laboratory
ATTN: AMSRL-BE-W (Dr. Seagraves) 1
Battlefield Environment Directorate
White Sands Missile Range, NM 88002-5501

USAF Rome Laboratory Technical
Library, FL2810 1
Corridor W, STE 262, RL/SUL
26 Electronics Parkway, Bldg 106
Griffiss AFB, NY 13441-4514

AFMC/DOW 1
Wright-Patterson AFB, OH 03340-5000

Commandant
U.S. Army Field Artillery School
ATTN: ATSF-TSM-TA (Mr. Taylor) 1
Fort Sill, OK 73503-5600

Commander
U.S. Army Field Artillery School
ATTN: ATSF-F-FD (Mr. Gullion) 1
Fort Sill, OK 73503-5600

Commander
Naval Air Development Center
ATTN: Al Salik (Code 5012) 1
Warminster, PA 18974

Commander
U.S. Army Dugway Proving Ground
ATTN: STEDP-MT-M (Mr. Bowers) 1
Dugway, UT 84022-5000

Commander
U.S. Army Dugway Proving Ground
ATTN: STEDP-MT-DA-L 1
Dugway, UT 84022-5000

Defense Technical Information Center ATTN: DTIC-OCP Cameron Station Alexandria, VA 22314-6145	2
Commander U.S. Army OEC ATTN: CSTE-EFS Park Center IV 4501 Ford Ave Alexandria, VA 22302-1458	1
Commanding Officer U.S. Army Foreign Science & Technology Center ATTN: CM 220 7th Street, NE Charlottesville, VA 22901-5396	1
Naval Surface Weapons Center Code G63 Dahlgren, VA 22448-5000	1
Commander and Director U.S. Army Corps of Engineers Engineer Topographics Laboratory ATTN: ETL-GS-LB Fort Belvoir, VA 22060	1
U.S. Army Topo Engineering Center ATTN: CPT-EC-7C Fort Belvoir, VA 22060-5546	1
Commander USATRADO ATTN: ATCD-FA Fort Monroe, VA 23651-5170	1
TAC/DOWP Langley AFB, VA 23665-5524	1

Commander Logistics Center ATTN: ATCL-CE Fort Lee, VA 23801-6000	1
Science and Technology 101 Research Drive Hampton, VA 23666-1340	1
Commander U.S. Army Nuclear and Chemical Agency ATTN: MONA-ZB, Bldg 2073 Springfield, VA 22150-3198	1
Record Copy	3
Total	86